How to protect groundwater catchments used for human consumption in karst areas?

Jean Carré, Georges Oller, Jacques Mudry

How to protect groundwater catchments used for human consumption in karst areas?

Jean Carré[1], Georges Oller[2] and Jacques Mudry[3]

[1]Ecole des Hautes Etudes en Santé Publique, Département santé environnement travail, avenue du professeur Léon Bernard 35043 Rennes cedex, Jean.Carre@ehesp.fr
[2]Agence Régionale de Santé Midi-Pyrénées, Délégation territoriale des Pyrénées Atlantiques, 64026 Pau cedex, Georges.Oller@ars.santé.fr
[3]CNRS Chrono-Environment Lab, Faculty of Sciences & Techniques, 16 route de Gray, F 25030 Besançon cedex, jacques.mudry@univ-fcomte.fr

Abstract

The natural variability of catchment waters in karst areas requires treatment in order to respect the turbidity limit in the water supply. This water treatment reduces the range to be expected from protection areas. The creation of immediate, main and satellite protection areas is necessary. The longitudinal extension proposed for the inner protection area is based on a water transit time of 2 hours for the highest speeds in the aquifer under consideration. Delineating the inner protection area in such a way serves as a buffer in the event of accidental pollution. The selected intervention timeline allows for the interruption of pumping and keeps extraction and treatment equipment safe. The implementation of an outer protection area corresponding to a caution area may supplement the protection.

1. Introduction:

In France, the establishment of protective areas for groundwater catchments intended for human consumption has been required since 1992. The 2004-2008 national health and environment plan imposed this requirement as of December 31, 2010 (MINISTÈRE DE LA SANTÉ, 2004). This objective has not yet been reached because as of today, only 59% of the 33,724 catchments have protection areas.

This delay is the result of the complexity of the procedure. Certain local authorities are hesitant to commit and individuals are often opposed to the constraints associated with the protection areas. In the departments with karst aquifers, special challenges related to the complexity of the water circulation and the absence of rules for appropriately sizing the protective areas, have increased the delay.

Failing to take into account specific characteristics of karst areas at the time of determining their boundaries has lead to failures with accordingly serious contamination of water, often followed by outbreaks of gastroenteritis.

As a consequence, the protection of water catchment facilities for karst waters requires a specific approach.

2. Protection zones in France

The concept of protection areas for catchments appeared in France for the first time in a law on hygiene dated December 15, 1902. However, it wasn't until water legislation was passed in 1964 that protective areas became obligatory for new catchments. The 1992 law broadened protection to all catchment facilities used for human consumption.

The protection established by the regulation includes an immediate protection area around the well that must be obtained. The inner protection area may prohibit or otherwise regulate facilities, construction, activities, warehouses, works, development or occupation of the land that may directly or indirectly harm the water quality. A outer protection area may be required, within which facilities, construction, activities, warehouses, works, development or occupation of the land may be regulated as mentioned above. The creation of satellite areas was introduced in 1989 to take karst specificities into account.

French legislation does not offer rules for sizing these areas, as exists in Germany, for example (SCHLEYER, 2001). The areas are delineated by a State certified hydrogeologist, in terms of the objectives set out in the regulation.

If the State formalizes the protection areas by promulgating a prefectural decree, the measure preceding this decree as well as the implementation of the protective areas and the application of the associated provisions in particular, is to be determined by the local authorities that own the catchment.

A guide published in 2008 by the ministry of health recalled that the protection areas aim to protect the catchment and not the entire water supply (MINISTÈRE DE LA SANTÉ, 2008). The provisions associated with these protection areas supplement the general regulations in terms of protecting the quality of catchment water.

Only the immediate protection area designed to protect the catchment facilities from harm is required, the other areas having been implemented depending on the vulnerability of the resource being exploited. For karst aquifers, which are especially vulnerable, the creation of an inner protection area and even a outer protection area is imposed.

The delineation of the areas depends on both occasional and accidental pollution risk. The pollution, primarily stemming from agriculture, is taken into account except for catchments with small drainage areas (roughly from 10 to 100 hectares), and the protection areas alone are not sufficient to handle this. Supplementary actions must be taken in conjunction with farmers regarding catchment areas not included in the protection areas.

The inner protection area is now associated with a buffer zone for accidental pollution and its extension must offer a reaction time in the event of such an occurrence.

As opposed to the inner protection area recognized on the grid and therefore enforceable to third parties; the outer protection area is typically traced on a small scale map. It is impossible to prohibit polluting activities and the provisions that apply only correspond to the strict application of the general regulations. Today, this protection area is associated with a caution area.

3. Specificities of karst aquifers

The karst aquifer is a heterogeneous area in which the voids have been organized by the water flow. This aquifer has privileged flow axes and drains in which the water transit speeds are quite high and linked to significant storage areas within the saturated zone. The fractures affecting the rock make up the easy movement routes enabling rapid infiltration, with slow filtration taking place small voids.

The overburden through which the infiltration occurs generally has limited filtering power. Drainage organization is also associated with a weak dilution effect and the dispersion of possible contaminants. The purification process is also limited by the short length of time the water stays in the aquifer.

The catchment gathering areas, the delineations of which are not always known with precision, are often spread out and can include land from several villages that are not necessarily users of this catchment water. It should also be recalled that karstification is a changing phenomenon, especially in chalk (BOUSQUET & SOUCHET, 1982).

In terms of protecting catchments, the slowing effects from soil cover or an epikarst are limited due to water transit speed which is often quite high, allowing polluting substances to enter the underground water supply quickly.

However, in aquifers where the pollution is quickly eliminated, the cumulative effects from one cycle to another are reduced. The size of the catchment gathering areas also offers the possibility of diluting pollution if this occurs sufficiently far enough upstream from the catchment area.

In terms of protecting catchment areas, karst areas appear more complex than surface areas. Access to the flows is prohibited and the upstream catchment areas are often quite large and where the duration of accidental pollution is brief.

Moreover, the temporal variability of the quality of catchment waters is a characteristic of the karst system and is explained by the existence of several drainage components. If the infiltrated water can undergo filtration in a dispersed way, favorable to the retention of certain contaminants in the ground or fissures, this is not the case for water which is engulfed by absorption areas (swallets). The infiltration of runoff water means severe degradation of the quality of catchment water marked by the appearance of turbidity and microbiological contamination but also by the possible presence of chemical contaminants from the catchment area. This was demonstrated by DUSSART-BAPTISTA *et al.* (2003), the high bacterial contamination associated with turbidity spikes can be maintained for decreasing values and weak turbidity values do not exclude contamination by microorganisms.

As a consequence, in karst aquifers, brief contamination episodes interrupt more or less long periods during which the catchment water is of good quality.

The presence of turbidity constitutes another obstacle to disinfecting catchment water. When turbidity reaches 1 NFU, disinfection is rendered inefficient. The survival of germs and the subsequent proliferation of bacteria in the reservoirs and the water mains system are encouraged. Turbidity can also cause strange tastes and odors, either directly or in reaction to the disinfectant, leading to the formation of deposits in the water mains system. Finally, the combination of certain organic materials with the disinfectant can also lead to the formation of haloforms.

Given the sanitary risks associated with turbidity, the public health code imposes a quality limit of 1 NFU at the water mains supply point for fissured groundwater showing significant periodic turbidity superior to 2 NFU. Prior to defining the protection area, this constraint requires examining the turbidity management measurements (bypass of turbid waters, storage of untreated quality water and/or its elimination through treatment.

The turbidity may be human induced but is most often linked to the picking up of sediment in suspension in the catchment area, generally via run-off water. In terms of drinking water quality one cannot, therefore, confuse poor water quality due to chronic turbidity and that linked to accidentally spilled pollutants.

The karst sectors are often used for agricultural purposes. If the karst of the chalk is sometimes cover with intensive cultures as in the Parisian Basin, karst areas are mostly sectors of relief where only extensive breeding is present and where potential contamination sources, both occasional and accidental, are nearly nonexistent. However, it is important to identify the quality parameters that may not respect the quality reference values or limits and to examine the methods to implement in order to correct this situation.

As a consequence, the study of the extracted drinking water must be placed before any consideration of protecting the catchment system.

4. Karst protection areas in France

If the inner protection area of the facilities in a karst sector has been sometimes defined as for those in porous areas, very early on hydrogeologists began to base the determination of the limits of the system and the analysis of its operation, so as to demonstrate the rapid flow and inventory the potential sources of pollution.

In 1977, considering the particular organization of the karst, Avias *et al.* [26] have suggested a delineation of the areas based on a vulnerability map synthesizing the information concerning surface transport, the fracturation and the level of karst coverage. This approach has been taken up and the multicriteria index methods have been supplemented with weighted systems developed by different authors (DOERFLIGER *et al*, 1997; AGENCE DE L'EAU ADOUR-GARONNE, 2010).

These methods demonstrate the interest of a spatialized representation with respect to a classic engineering approach, criteria analysis, which is apparently easy to implement. It involves a scoring system that uses a combination of simple ratios to constitute a synthetic indicator which provides information on the degree of vulnerability. However despite a strict appearance, these methods do not take into account the level of knowledge which is inevitably unequal from one grid square to the next. Certain criteria, such as the knowledge of epikarst and karstification, are not easily accessible. The weight granted to a criterion is subject to subjectivity and in the end, the classification may be modified. Finally, these methods are complex and costly or lead to simplifications that derive from traditional approaches (map of slopes, caves, ground presence or lack thereof, etc.) that suffice to imagine the changes to be performed on the catchment gathering areas.

If these maps supply information about the vulnerability of the resource, as PÉTELET-GIRAUD *et al* (2000) points out, they do not lead to a delineation of the areas in terms of the vulnerability variability, which is often quite high. This will lead to envisioning a fractioning of the protection areas, making their implementation difficult.

A guide published in 2010 (AGENCE DE L'EAU ADOUR-GARONNE) presents an isochronous curve to determine the areas to be included in the inner protection area. The water transit times used are between 12 and 48 hours depending on the existence of a complete treatment of the collected water and/or a substitution resource and/or warning system. The transit times used are not well-suited to managing accidental pollution. The areas to include in the protection area are concentrated around the catchments but these are still quite large and difficult to implement or correspond to cave areas situated several kilometers upstream of those that must be placed in the satellite protection areas.

5. Proposed protective approach

There is no need for a hydrological study to identify the karst nature of a resource located in carbonate soil. The quality variations of the extracted water and the existence of turbidity peaks in particular, attest to this characteristic. It is therefore necessary to envisage either a thorough treatment of the water or, for small catchments, turbidity episode management.

It is then possible to work on the delineation of the protection area for the catchment under consideration. The definition of the immediate protection area does not pose any particular challenges within the karst context. In this area, only activities relating to water collection are authorized.

It may also be necessary to create satellite protection areas around the absorption areas for run-off water. The classification of these satellites in immediate protection areas, which is performed when the municipality acquires the land, enables the carrying out of developments designed to slow the infiltration and hold back a fraction of the sediment transport (SOUCHET, 2006).

The implementation of water treatment reduces the role of protection areas and can, like surface water; be accompanied by a reduction in their surface (AGENCE DE L'EAU ADOUR GARONNE, 1999). It is proposed to retain only a sector of the catchment area for the inner protection area, upstream from the catchment. The longitudinal extension corresponds to a water transit time of 2 hours for the highest known speeds in the karst aquifer under consideration. This extension area offers a reaction time for the catchment manager in the event of accidental pollution and functions as an expected buffer zone for the inner protection area. The two-hour time differential as regards the accidental pollution's arrival allows for the catchment and treatment facilities to be secured by interrupting pumping. Stopping pumping must be compensated by a substitution resource, such as the use of treated stored water or interconnections. The latter are generally difficult to perform in areas of relief.

In this area, the provisions to be applied are intended to prevent the installation of new activities by initiating, for example, a "no-build" zone for certain lots.

An outer protection zone extending all or part of the way into the water catchment area not included in the inner protection area shall be created. In this area, regional planning measures suited to the karst context will be applied. An incentive to implement operations to improve agricultural practices can be required. In the event that risky activities are present, an emergency plan identifying all of the risky activities for the water quality will be drafted. The installation of a pollution detection system can be justified in the event of significant industrial risk.

6. Conclusion

Water catchments protection in karst aquifers is more complex than those of catchments in surface waters. The rapid variations in the water quality that are accompanied by turbidity spikes in particular, generally associated with microbiological contamination, are a given in karst areas and the implementation of water treatment is required. The role of protection areas in securing water quality is found to be of reduced importance. It is therefore proposed to limit the inner protection area to a sector of the water catchment system that is sufficiently extended to serve as a buffer zone in the event of accidental pollution. As with surface water, the quality of drinking water lies more in a secure rather than a protective approach, as one understands for catchments located in porous aquifers.

References

SCHLEYER R *et al.*, 1992, Wellhead protection zones in Germany: delineation, research and management, *Journal of the Institution of Water Environmental Management*, 6, 303-311.

MINISTERE DE LA SANTE ET DE LA PROTECTION SOCIALE *et al.*, 2004, Plan national santé environnement 2004-2008. La Documentation française, 90 p.

MINISTERE DE LA SANTE, DE LA JEUNESSE ET DES SPORTS, 2008, Guide à l'usage des hydrogéologues agréés en matière d'hygiène publique et des services de l'état en charge de la santé, 53 p.

BOUSQUET G. & SOUCHET G., 1982, Contamination dans un karst de la craie, Actes 3ème colloque d'hydrologie en milieu calcaire, 9-22.

DUSSART-BAPTISTA L. *et al.*, 2003, Transfer of bacteria-contaminated particles in a karst aquifer: evolution of contaminated materials from a sinkhole to a spring, *Journal of Hydrology*, 284, 285-295.

AVIAS J., 1977Sur les principes et sur la méthodologie pratique de protection des aquifères karstiques, Colloque « Protection des eaux souterraines captées pour l'alimentation humaine thème 3, Orléans, 1-2 mars, 7-11.

DOERFLIGER N *et al.*, 1997; Vulnérabilité des captages en milieu karstique : Nouvelle méthode de délimitation des zones de protection : méthode multicritère EPIK, GWA. *Gas, Wasser, Abwasser*, 77, 5, 295-302.

AGENCE DE L'EAU ADOUR GARONNE, 2010, Stratégies de protection des ressources karstiques utilisées pour l'eau potable, guide pratique, 80p.

AGENCE DE L'EAU ADOUR GARONNE, 1999, Etude n°75, Protection des prises d'eau de surface, Quelles stratégies ? 59 p.

PETELET-GIRAUD E. *et al.*, 2000, RISKE : méthode d'évaluation multicritère de la cartographie de la vulnérabilité des aquifères karstiques, *Hydrogéologie*, 4, 71-88.

SOUCHET G., 2006, Aménagement des bétoires et des « points noirs » dans un karst de la craie, communication, Colloque « Les Ressources en eau en milieu karstique », Rouen, 4 et 5 mai.